T-ray specs

Radiation from a previously unexploited region of the electromagnetic spectrum could hold the key to a new generation of security devices. Catherine Zandonella investigates.

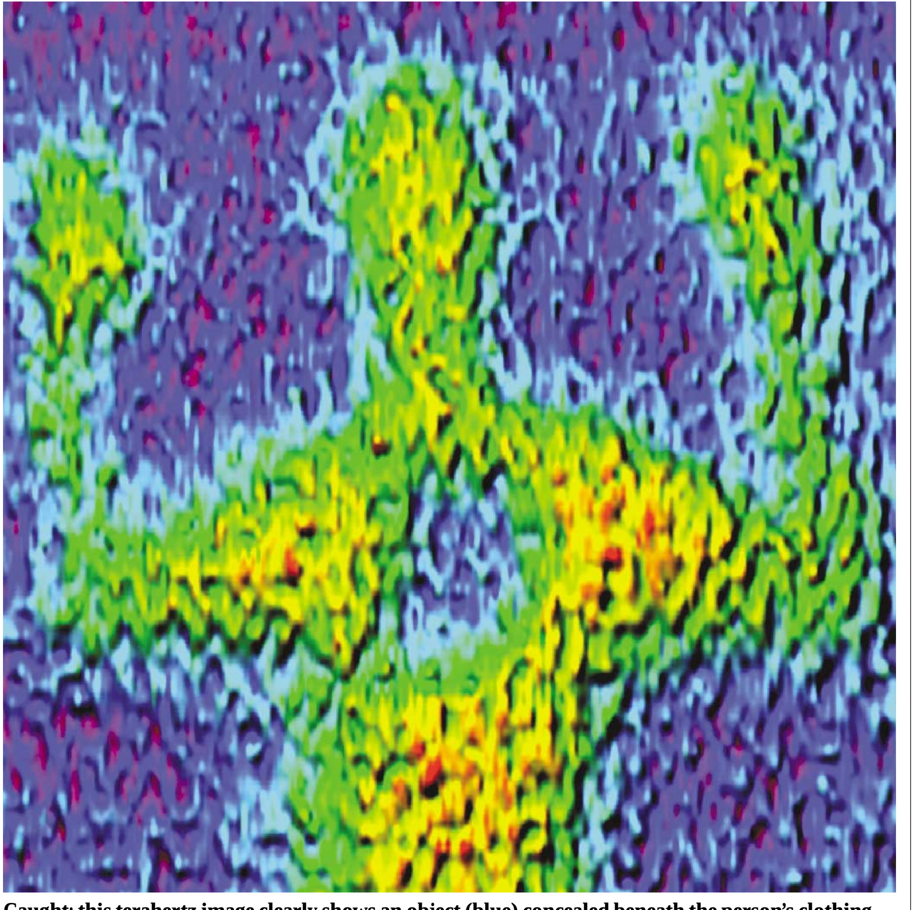
Suicide bombers, plastic explosives strapped to their bodies, approach the turnstiles at a packed football stadium. The security guards don't have time to search every spectator, and even if a metal detector were installed, it would miss the terrorists' deadly cargo. But a novel device that can see through the bombers' clothing succeeds were other systems fail. Security personnel are alerted, and surround the attackers before they can strike.

Such is the potential power of a new imaging technology. Terahertz devices, so named because they detect electromagnetic radiation in the terahertz frequency range (1 THz is 10^{12} Hz), promise to peer through clothing, revealing concealed weapons and explosives. The technique could also be used to seek out structural defects in materials, to detect skin cancer or to provide new information about astronomical objects.

For years, radiation with a frequency of between 0.1 THz and 10 THz languished unexplored. But recent advances in generating and analysing such radiation, together with an avalanche of research funding for antiterror applications, are now helping researchers to examine its applications.

Terahertz radiation, often called T-rays, lies between microwaves and infrared light in the electromagnetic spectrum. It can sail through paper and clothing, but not very far through skin or biological molecules, so objects hidden beneath clothing can be revealed by analysing the way in which the radiation is scattered and reflected off individuals. And because biological molecules absorb different frequencies of terahertz radiation, it may even be able to show whether a seemingly innocuous white powder is actually something more sinister such as anthrax.

That such goals seem achievable owes a lot to two landmark developments in terahertz research. One breakthrough came in the form of an imaging technique known as time-domain terahertz spectroscopy[1], which was was developed at Bell Laboratories in Murray Hill, New Jersey, in the mid-1990s. Rapid bursts of visible light are fired at a semiconductor crystal, which absorbs the radiation and re-emits it as pulses of terahertz waves, which are then directed at the object to be imaged. Some of the radiation passes into the object and bounces off its internal layers. By scanning the pulses across the target and measuring the time it takes for the reflected



TAKEN WITH RUTHERFORD MK 2 IMAGING SYSTEM

Caught: this terahertz image clearly shows an object (blue) concealed beneath the person's clothing.

radiation to reach a detector, researchers can build up a three-dimensional image of what is under the object's surface.

Light work

A more recent advance came from a team led by Alessandro Tredicucci, a photonics researcher at the National Enterprise for Nanoscience and Nanotechnology in Pisa, Italy. Terahertz research had been handicapped by the fact that the only lasers that could produce terahertz radiation were huge devices that filled buildings or which required extreme operating conditions. Tredicucci's team cracked the problem last May[2], when it produced a terahertz laser just a few millimetres in size.

Lasers use electricity to boost electrons to higher energy levels: the electrons emit light when they fall back to a lower level, and the frequency of that light depends on the gap between the levels. The energy gaps in various materials are suitable for producing infrared or visible light, but Tredicucci's group, working with a team at the University of Cambridge led by Giles Davies, was the first to create a material that could generate terahertz radiation. They used a semiconductor crystal made from alternating layers of gallium arsenide and aluminium gallium arsenide. The layers allow electrons to cascade through a serious of energy levels, emitting a photon each time to give a 'quantum cascade' terahertz laser.

Xi-Cheng Zhang, a pioneer of terahertz imaging at Rensselaer Polytechnic Institute in New York, is one of the researchers capitalizing on such advances. He was approached in April by Lockheed Martin Space Systems in New Orleans, which made the insulating foam implicated in the space shuttle Columbia disaster. One of the shuttle's wings was damaged during take-off by a chunk of foam that fell off the fuel tank, and this is believed to have caused the craft's destruction as it returned to Earth. Lockheed wanted to see whether terahertz imaging could check for defects in the foam before the launch of future missions.

The company sent Zhang a block of foam with four holes hidden in it, the smallest just 6 millimetres across. Using time-domain spectroscopy, Zhang's team monitored the reflection of terahertz waves from inside the foam and spotted all four holes. The group is now running a feasibility study to see whether the technology can be used to test all of the foam used on a shuttle's tanks.

Zhang's team is also working on security applications. Shortly after the 2001 US anthrax attacks, during which envelopes containing anthrax were posted to politicians and media outlets, Zhang and his colleagues began investigating whether terahertz radiation could help to prevent similar events in the future. They used envelopes containing various white powders — flour, sugar, talcum powder and spores of a benign species of bacterium, which acted as a surrogate for anthrax — and found that they could detect a characteristic absorption signature for the spores[3]. Several groups, including a team led by Daniel van der Weide, an electrical engineer at the University of Wisconsin in Madison, are doing similar work in an attempt to develop a mail sorter that can check for biological hazards.

RENSSELAER POLYTECHNIC INSTITUTE

What lies within: researchers have successfully used terahertz radiation to spot internal defects in insulating foam (inset) for the space shuttle.

Snap happy

But firing terahertz radiation at an object is not the only way to get an image. All objects naturally emit the radiation and so can be imaged using an appropriate detector. Last autumn, an international consortium of industrial and academic researchers known as StarTiger built the first such device. The work was sponsored by the European Space Agency, which hopes to use StarTiger's camera to study terahertz radiation emitted by astronomical objects such as gas clouds.

The camera's potential security applications are now being explored by researchers at the Rutherford Appleton Laboratory near Oxford, UK, where StarTiger was hosted. Scientists there believe that the camera will detect concealed objects such as plastic explosives from tens of metres away. In a feasibility test, they took images of people last month (see previous page), and they are now working on increasing the camera's resolution to an appropriate level for practical applications.

Such work has caught the attention of the US military. The Army Research Office in Research Triangle Park, North Carolina, is funding research aimed at producing similar devices. But, unlike the Rutherford Appleton team, the military argues that relying on naturally emitted radiation does not give a strong enough signal, so it wants its devices to include their own terahertz radiation emitter.

Generating sufficient power to illuminate a target is difficult, and current devices are a long way off this goal. Terahertz waves below 0.5 THz are used, as higher frequencies are absorbed by water vapour and can't travel more than about a metre through air. To produce these signals, physicists use a microwave emitter and convert this radiation into T-rays with frequency multipliers, which insert extra cycles into the chain of electromagnetic waves. But these multipliers are very inefficient, so it is difficult to get sufficient power for a clear image. Van der Weide believes that by improving the multipliers and the antennas that emit the radiation, he will be able to make a device that can image hidden objects, such as landmines, from 10 metres away with greater resolution than the Rutherford group's camera can achieve.

How low can you go?

For detecting biological molecules, the relative absorption of terahertz radiation is key. But to test for a wide range of materials, you need a laser that emits across a broad range of frequencies. Although Tredicucci's laser is promising, it can only operate at a fixed frequency. Initially this was 4.4 THz, but his team, and other groups, have recently made lasers that go as low as 2.5 THz, and they are confident of pushing the frequency lower.

These lasers could be used to seek out biomolecules that absorb terahertz radiation at specific frequencies, although Tredicucci and others are trying to make a laser whose frequency can be tuned across a limited frequency range. Another problem that the researchers face is that the lasers need to be cooled to below 100 kelvin using liquid nitrogen — a cooling system that cannot fit on a hand-held device. This is not a drawback for all applications — a mail-sorting device, for example, would not need to be portable.

But the detection of biological agents also carries a risk that scattering could be mistaken for absorption. Particles that are roughly the same size as the wavelength of terahertz radiation, such as fine sand about 1 mm across, will scatter specific frequencies, creating a signal similar to an absorption spectrum. In addition, there is the question of safety. Researchers believe that their devices are safe, as they produce radiation at power levels well below those used by mobile phones, but only limited work has been done on the effect of terahertz radiation on living tissue.

Although it seems that terahertz technology has a number of unresolved issues, researchers are not particularly concerned. "The field is in its adolescence," says Roger Appleby, a physicist with defence company QinetiQ in Malvern, UK. "It is unfair to compare terahertz to more mature fields."

If Appleby's confidence is justified, terahertz radiation could go from being a backwater of the electromagnetic spectrum to a region that makes possible a new generation of security devices. Tredicucci, for one, is in no doubt. "If you need to detect something hidden," he says, "this is the region with which to do it." ■

Catherine Zandonella is a freelance writer in New York.

1. Hu, B. B. & Nuss, M. C. *Opt. Lett.* **20,** 1716–1718 (1995).
2. Köhler, R. *et al. Nature* **417,** 156–159 (2002).
3. Wang, S., Ferguson, B., Abbott, D. & Zhang, X.-C. *J. Biol. Phys.* **29,** 247–256 (2003).